SYSTEM AND METHOD FOR BI-DIRECTIONAL OPTICAL COMMUNICATION USING STACKED EMITTERS AND DETECTORS

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of Application No. 09/384,112, filed August 26, 1999, which claims the benefit of U.S. Provisional Application No. 60/098,049, filed August 26, 1998, and U.S. Provisional Application No. 60/097,946, filed August 26, 1998.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

The U.S. government has a paid-up license in this invention and the right in limited circumstances to require the patent owner to license others on reasonable terms as provided for by the terms of EEC-9402723 awarded by the National Science Foundation of the U.S.

TECHNICAL FIELD

The present invention relates generally to the field of communications, and more particularly, to a system and method for optical bi-directional communication.

BACKGROUND OF THE INVENTION

Current communications systems and networks are becoming faster and more complex, using any one of number of mediums. Communication using these systems and networks is typically bi-directional in that signals are exchanged between two sources as they communicate for various purposes. More recently, fiber optic networks have been employed as the medium for communications. Typically, the optical fibers themselves may be very small and, consequently, coupling various devices to the optical fibers to create a communications link can be difficult and expensive.

An additional problem with current optical fiber communications systems is that optical fibers are often used for unidirectional communications. This is due in part to the difficulty of physically transmitting and receiving an optical signal on a single optical fiber that may be, for example, a single micron thick. Unfortunately, this results in the need for two optical fiber links to establish bi-directional communications.

SUMMARY OF THE INVENTION

Embodiments of the present invention include a bi-directional optical link and method to facilitate bi-directional optical communications with a single optical fiber. Briefly described, in one embodiment the bi-directional optical link comprises a thin film detector having an upper surface facing a predetermined direction to receive incident

light. Also, the link includes a thin film emitter stacked over the upper surface and oriented to direct a beam of light toward the predetermined direction. The thin film detector is relatively wide and flat, where the thin film emitter can be placed on the thin film detector while occluding only a portion of the thin film detector. Thus, the thin film detector can receive incident light from a single optical fiber facing the emitter/detector from the predetermined direction while at the same time emitting a beam of light into the same single optical fiber.

Embodiments of the present invention can also be viewed as including methods for establishing a bi-directional communications link. In this regard, in one embodiment the method can be broadly summarized by the steps of positioning a thin film detector having an upper surface so as to face a predetermined direction to receive incident light, stacking a thin film emitter over the upper surface, and, orienting the thin film emitter to direct a beam of light toward the predetermined direction.

Other features and advantages of the present invention will become apparent to one with skill in the art upon examination of the following drawings and detailed description. It is intended that all such additional features and advantages be included herein within the scope of the present invention.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

The invention can be better understood with reference to the following drawings. The components in the drawings are not necessarily to scale, emphasis instead being placed upon clearly illustrating the principles of the present invention. Moreover, in the

drawings, like reference numerals designate corresponding parts throughout the several views.

FIG. 1A is a drawing of a bi-directional communications link according to an embodiment of the present invention;

FIG. 1B is a top view of the bi-directional communications link of **FIG. 1A**;

FIG. 2A is a side view drawing of a detector used in the bi-directional communications link of **FIGS. 1A** and **1B**.

FIG. 2B is a bottom view drawing of a detector used in the bi-directional communications link of **FIGS. 1A** and **1B**;

FIG. 3 is a drawing of a bi-directional communications link according to another embodiment of the present invention;

FIG. 4A is a drawing of a bi-directional communications link using an intermediate host according to another embodiment of the present invention; and

FIG. 4B is a bottom view of the intermediate host assembly of **FIG. 4A**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

With reference to **FIG. 1A**, shown is a bi-directional optical link **100** according to an embodiment of the present invention. The bi-directional optical link **100** includes a stacked arrangement of a thin film detector **103** and thin film emitter **106**. The detector **103** is located on a host substrate **109** as shown. The detector **103** is preferably flat in shape with a relatively small thickness. The detector **103** includes an upper surface **113** oriented to receive incident light **116** from a predetermined direction **123**, that is, for example, normal to the upper surface **113**. The incident light **116** propagates, for

example, from an optical fiber **119** as shown where the optical fiber **119** has a core **126** and a cladding **129**. The emitter **106** is stacked over the detector **103**. Both the detector **103** and the emitter **106** include electrical contacts from which these devices are driven. Both the detector **103** and the emitter **106** are independently optimized and bonded, for example, to a transceiver circuit (not shown) located on the host substrate **109**.

The detector **103** and the emitter **106** may be bonded to the transceiver circuit using a variety of materials, including metals, conductive polymers, and conductive epoxies, *etc*. In addition, either thick or thin bonds may be used to adhere and electrically connect the detector **103** and the emitter **106** to a transceiver or other circuit on the host substrate **109**. These thick or thin bonds may include a circuit, glass, plastic, laminate, polymer, *etc.*

During operation of the bi-directional optical link **100**, the emitter **106** generates a beam of light **133** that propagates in the predetermined direction **123** into the core **126** of the optical fiber **119**. Generally, the optical fiber **119** is positioned so as to receive the beam of light **133** and to ensure that the incident light **116** propagates from the optical fiber **119** onto the upper surface **113** of the detector **103**. In other words, the end of the optical fiber **119** is positioned so as to face the detector **103** from the predetermined direction **123**. Both the incident light **116** and the beam of light **133** are modulated accordingly. In this manner, the bi-directional optical link **100** advantageously allows a single optical fiber **119** to be used for bi-directional communications.

The emitter **106** may be, for example, a vertical cavity surface emitting laser or a light emitting diode (LED), or other suitable light source. The actual component chosen as the emitter **106** depends in part on the capabilities and attributes of the component and

the particular application. For example, vertical cavity surface emitting lasers allow higher speed operation than LED's, but also include higher power consumption. The emitter **106** includes electrical contacts that are bonded to the host substrate **109** using suitable conductive bonding agents such as, for example, metals, conductive polymers, conductive epoxies, or other suitable conductive bonding agents. In particular, the electrical contacts are preferably bonded to counterpart electrical contacts on the host substrate **109**, where the circuit that drives the emitter **106** is also located on the host substrate **109**.

The leads that run between the emitter **106** are located over the detector **103** in order to reach the emitter **106**. These leads are relatively small in width resulting in minimal occlusion of the detector **103** and may be placed over a transparent insulation layer placed over the detector **103** as will be discussed. Likewise, the detector **103** includes electrical contacts that are bonded to the counterpart contacts on the substrate **109** in a similar manner to the emitter **106**.

The host substrate **109** may comprise, for example, an actual circuit, glass, plastic, laminate, polymer, or other material, *etc.* The optical fiber **119** is held into place using suitable means.

Turning to **FIG. 1B**, shown is a top view of the bi-directional optical link **100**. The detector **103** is spherical in shape with a diameter **d**, for example, that is larger than the diameter **c** of the core **126**, and, given its relatively small thickness, is in the shape of a disk. The emitter **106** is generally located over the detector **103** at a position approximately near the center of the detector **103**. Interposed on the detector **103** are

outlines of the core **126a** and **126b** of the optical fiber **119 (FIG. 1A)** in first and second positions over the detector **103**.

The first and second positions of the cores **126a** and **126b** illustrate a positioning tolerance of the bi-directional optical link **100** that is a significant advantage of the present invention. The core **126a** is shown substantially centered in the detector **103**, whereas the core **126b** is off to the side. However, the emitter **106** is still positioned within the periphery of both cores **126a** and **126b**, thus resulting in the propagation of the beam of light **133 (FIG. 1A)** into the core **126** of the optical fiber **119**. It is a significant advantage that the optical fiber **119** need only be positioned relative to the detector **103** and the emitter **106** so as to capture the beam of light **133** generated by the emitter **106**, while at the same time, illuminating enough of the detector **103** with the incident light **116 (FIG. 1A)** so as to be detectable. This is due, in part, to the relatively large diameter **d** of the detector **103** and the relatively small size of the emitter **106**. In terms of actual measurements, for example, given that the diameter **c** of the core **126** is approximately 1 micron, and the diameter of emitter **106** is much smaller, the core **126** may be positioned over the detector **103** off center by the positioning tolerance X. Note, however, that the emitter **106** may be any size or shape.

The size of the emitter **106** is optimized, keeping a couple of competing parameters in mind. On one hand, one wishes to maximize the size of the emitter **106** to ensure that a beam of light **133** of maximum size is generated and coupled into the optical fiber **119**. On the other hand, one wishes to minimize the size of the emitter **106** to reduce the occlusion of the detector **103** by the emitter **106**. Thus, the actual sizes chosen for the emitter **106** should be specified with these competing interests in mind.

Specifically, one should determine the size of the emitter **106** in light of the desired strength of the beam of light **133** that is to be transmitted through the optical fiber **119** as well as a desired signal strength from the detector **103** in a worst case position of the optical fiber **119** over the detector **103**.

With reference to **FIGS. 2A** and **2B**, shown are side (**FIG. 2A**) and bottom (**FIG. 2B**) views of an inverted metal-semiconductor-metal (MSM) photodetector **103a** that is preferably employed as the detector **103** (**FIGS. 1A** and **1B**). The MSM photodetector **103a** is described in detail in Jokerst, N. M. et al., <u>Thin Film Inverted MSM Photodetectors</u>, IEEE Photonics Technology Letters, Vol. 8, No. 2, (February 1996), that is incorporated herein by reference in its entirety. It is understood, however, that any detector that provides a suitable physical shape and electrical properties may be employed as the detector **103**.

To provide an overview, the MSM photodetector **103a** includes a first portion **139** of semiconductor material that generates photogenerated excess carriers when exposed to the incident light **119**. The photodetector **103a** also includes electrodes **143** and **146** with inter-digitated fingers **149**. When a bias voltage is applied to the inter-digitated fingers, an electric field is formed between the adjacent fingers **149** that causes the photogenerated excess carriers to be swept from the semiconductor material into the fingers, creating a photocurrent that is proportional to the power of the incident light **119**.

With respect to **FIG. 3**, shown is a bi-directional optical link **100a** according to another embodiment of the present invention. The bi-directional optical link **100a** includes a detector **103a** with electrodes **143/146**. The electrodes **143/146** are electrically coupled to contacts of a transceiver circuit, for example, located on the host substrate **109**

via conductive "bump bonds" **153**, the bump bonds being known to those skilled in the art. In fact, the bump bonds **153** are the mechanism by which the detector **103a** is originally held to the host substrate **109**. Thereafter, a first insulation layer **156** is placed over the detector **103a**. The materials used to create the first insulation layer **156** are transparent with respect to the incident light **116** so as to allow the incident light **116** to reach the detector **103a**. Such materials are generally known to those skilled in the art.

Placed on the first insulation layer **156** is a first electrical lead **159** to connect a first contact of the emitter **106** to a corresponding contact on the host substrate **109**. A second insulation layer **163** is located over the first electrical lead **159** and surrounds the emitter **106**. The second insulation layer **163** may be comprised of the same materials as the first insulation layer **156**. A second electrical lead **166** is placed on top of the second insulation layer **163** that electrically connects a second electrical contact of the emitter **106** to a counterpart contact on the host substrate **109**. Thus, the emitter **106** is driven by the transceiver circuit located on the host substrate **109** via the first and second electrical leads **159** and **166**. Likewise, the photocurrent generated by the detector **103** is provided to the transceiver circuit via the electrical connections established by the bump bonds **153**.

With reference to **FIG. 4A**, shown is a bi-directional optical link **100b** according to another embodiment of the present invention. The bi-directional optical link **100b** includes a detector **103a** and an emitter **106** bonded to an intermediate host **169** as shown. The detector **103a** includes first and second detector leads **173** and **176** that electrically couple the electrodes **143/146** of the detector **103a** to the bump bonds **183** as shown. The emitter **106** includes contacts that are coupled to bump bonds **186** via first and second

emitter leads **189** and **193**. Insulation material **196** is located at various points as shown to hold the various components in position. The intermediate host **169** with the detector **103** and the emitter **106** is bonded to the substrate host **109** via the bump bonds **183** and **186** that adhere to appropriate contacts **199** on the substrate host **109**. The intermediate host **169** is comprised of a transparent material to allow both the beam of light **133** and the incident light **116** to travel therethrough. **FIG. 4B** shows a bottom view of the bi-directional optical link **100b** of **FIG. 4A**.

Many variations and modifications may be made to the above-described embodiment(s) of the invention without departing substantially from the spirit and principles of the invention. All such modifications and variations are intended to be included herein within the scope of the present invention.